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# MARINE PHYSICS: INTERNAL-SURFACE WAVE INTERACTION AND MICROSTRUCTURE MEASUREMENT PROGRAM

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Scripps Institution of Oceanography

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This semi-annual report reflects the technical status of internal/surface wave interaction and microstructure projects conducted within the Advanced Ocean Engineering Laboratory at the Scripps Institution of Oceanography. These projects are: (1) Thermal Microstructure - to examine in detail the structure and dynamics of temperature and salinity and (2) Atmospheric Boundary Layer - to provide an understanding of the interaction between atmospheric boundary effects and surface waves.

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ADVANCED OCEAN ENGINEERING LABORATORY

TECHNICAL PROGRESS REPORT

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY

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# PART I: MICROPROCESSES

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## PART I: MICROPROCESSES

### I. PROJECT SUMMARY

This project aims to describe the small scale spatial variations of temperature, salinity and velocity in the ocean and to understand how these variations are created and decay.

Studies during this year have emphasized the importance of intrusions of one water mass into another for the generation of microstructure. At the boundaries of intrusions the intensity of temperature and salinity microstructure tends to be very much larger than in the interior of a water mass.

Development of a new instrument, capable of measuring velocity microstructure, is well underway.

### II. TECHNICAL REPORT

The essence of physical oceanography is the study of the budgets and transfer processes of momentum, heat, and salt in the ocean. Microstructure observations are concerned with those processes which affect the final dissipation of fluctuations of momentum, heat, and salt by the action of molecular viscosity and diffusivity. With the energy dissipation rates typical of the ocean, viscosity smooths the velocity fluctuations smaller than a few centimeters. Appreciable temperature fluctuations exist to slightly smaller scales, while salinity fluctuations may persist to tenths of a millimeter.

Instrumentation capable of resolving centimeter scale temperature fluctuations was developed by C. S. Cox at Scripps in 1968. A modern version of the system is described by B. P. Johnson (in progress). A conductivity probe with comparable resolution was reported by Gregg and Cox (1971). The temperature measurements fall somewhat short of complete resolution in highly active regions, but achieve this objective below several hundred meters in depth. However, estimates of the dissipation to within a factor of 10 can be made, even within the most vigorous regions. The salinity fluctuations, computed from the simultaneous temperature and conductivity data, do not permit salt dissipation estimates but have been very useful in identifying small-scale fluctuations in the density field; such information is necessary to understand the physical processes producing the microstructure.

Using this instrumentation, measurements have been made at various locations in the Pacific over the past four years. Data were obtained from several sites in the California Current, the middle of the northern and southern subtropical gyres, and the equator. Three cruises were made to the same station, 28°N, 155°W, in the northern subtropical gyre to determine if seasonal variations could be observed. The latitude of these observations is the same as the MODE site and will provide a basis for comparisons of the Atlantic and Pacific.

The results of this work to date have been reported, for the California Current, by Gregg and Cox (1972) and, for the first of the mid-gyre cruises, by Gregg, et al. (1973). Another paper by Gregg, entitled "Microstructure and Intrusions in the California Current", has recently been submitted for publication to the JOURNAL OF PHYSICAL OCEANOGRAPHY. The attached figures, taken from this paper, show the great differences in vertical structure, with scales of 10-30 meters, which can exist over horizontal separations of a few kilometers. Figure 1a shows a monotonic temperature record and a moderately steppy, but stable, density profile, while 1b shows multiple temperature inversions and some pronounced density instabilities. Figure 2 shows that the one record has a nearly linear TS relation while the other has a very wiggly trace. When the three water masses present in the area are superimposed on the diagrams, the first record consists of solely equatorial water while the second exhibits multiple intrusions between the water masses. As seen in Figure 3, the boundaries of these intrusions are associated with very high levels of temperature dissipation; variations of $10^7$ in the dissipation are found when 0.5 m averages are formed from this record.

Although analysis of much of the remaining data is not complete, several conclusions seem rather clear:

(1) The most active microstructure, in terms of the variance of the temperature gradient, is found in association with larger scale (5 to 30 m) stable temperature inversions in the vertical profile. This is true even when the rms gradients are normalized with respect to the mean gradients.

(2) The normalized microstructure levels in the mid-gyre are a factor of 10 to 1000 below those in regions such as the California Current. The apparent reason is the lack of strong intrusions in the mid-gyre.

(3) There are significant variations, partly seasonal, in the mid-gyre levels. Below the near surface region, this variability is associated with the occurrence of weak intrusive features - even to depths of 700-800 m.

(4) Both double diffusivity processes and shear instabilities act to dissipate the intrusions.

Work is progressing on a new microstructure recorder which will have a capability for velocity microstructure measurements in addition to temperature and conductivity/ salinity. The instrument is a free-fall device with internal recording. The most difficult aspect is determining the aspect and position of the instrument with sufficient precision that the relative velocity measurements can be translated into meaningful absolute measurements. During the year numerical and analogue model studies of the falling attitude of the body have been carried out as well as a study of methods of measurement and analysis of the motions of the actual instrument.

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Gregg, M. C.; C. S. Cox and P. W. Hacker (1973) Vertical microstructure measurements in the central North Pacific. J. Phys. Oceanogr., 3(4):458-469.

## FIGURE CAPTIONS

Figure 1. Temperature, salinity and density profiles from data points averaged over 0.03 m. The two records were taken off Cabo San Lucas on successive days with a horizontal separation of about 10 km.

Figure 2. TS diagrams plotted from the profiles in Figure 1.

Figure 3. In each figure the two leftmost traces are temperature and temperature gradient taken from the deconvolved high-gain profiles. Only every 32nd point has been plotted. The remaining plots represent averages made over successive 0.5 m blocks of the deconvolved data. Proceeding from left to right they are: mean temperature gradient, rms temperature gradient, cumulative contribution to the variance of the temperature gradient, and the mean density gradient. The solid lines represent the respective mean values for the entire record.

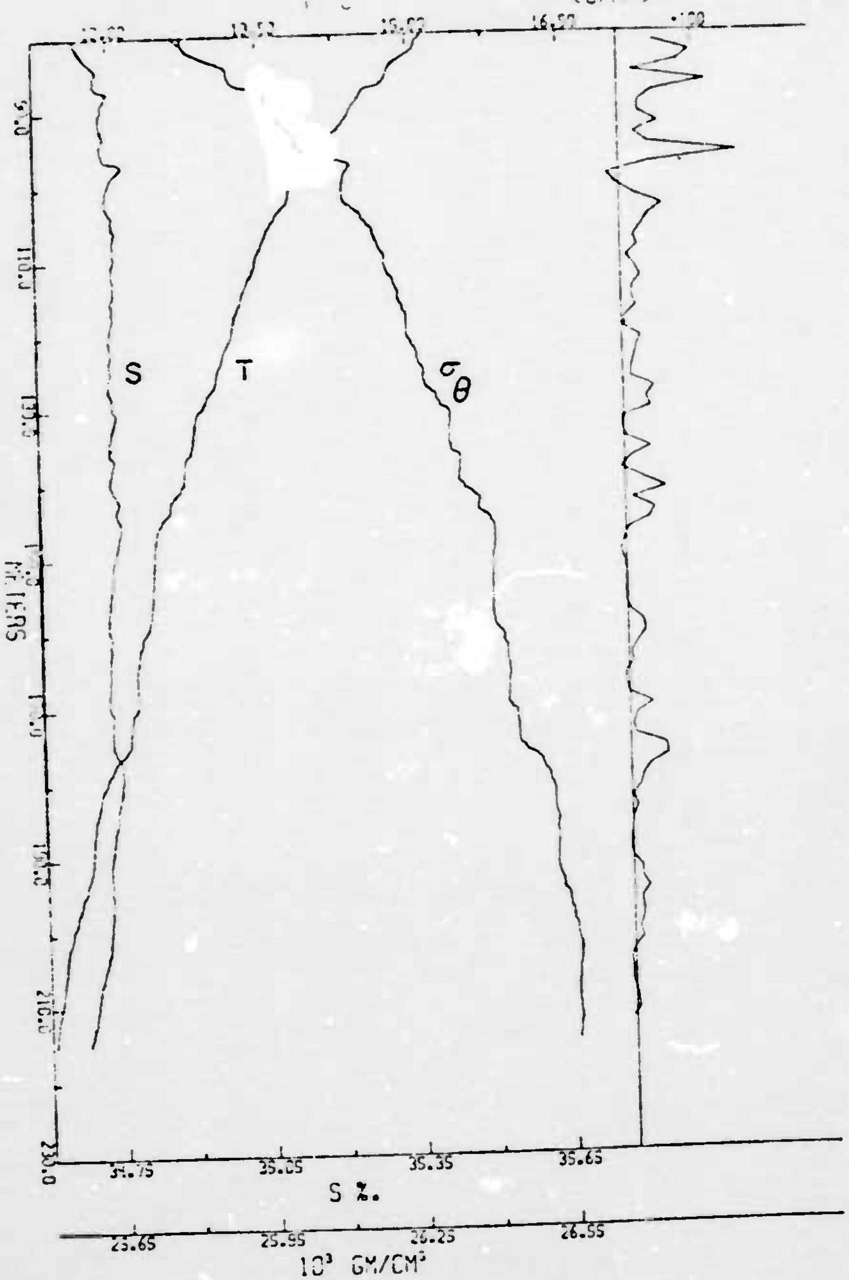


Figure 1a

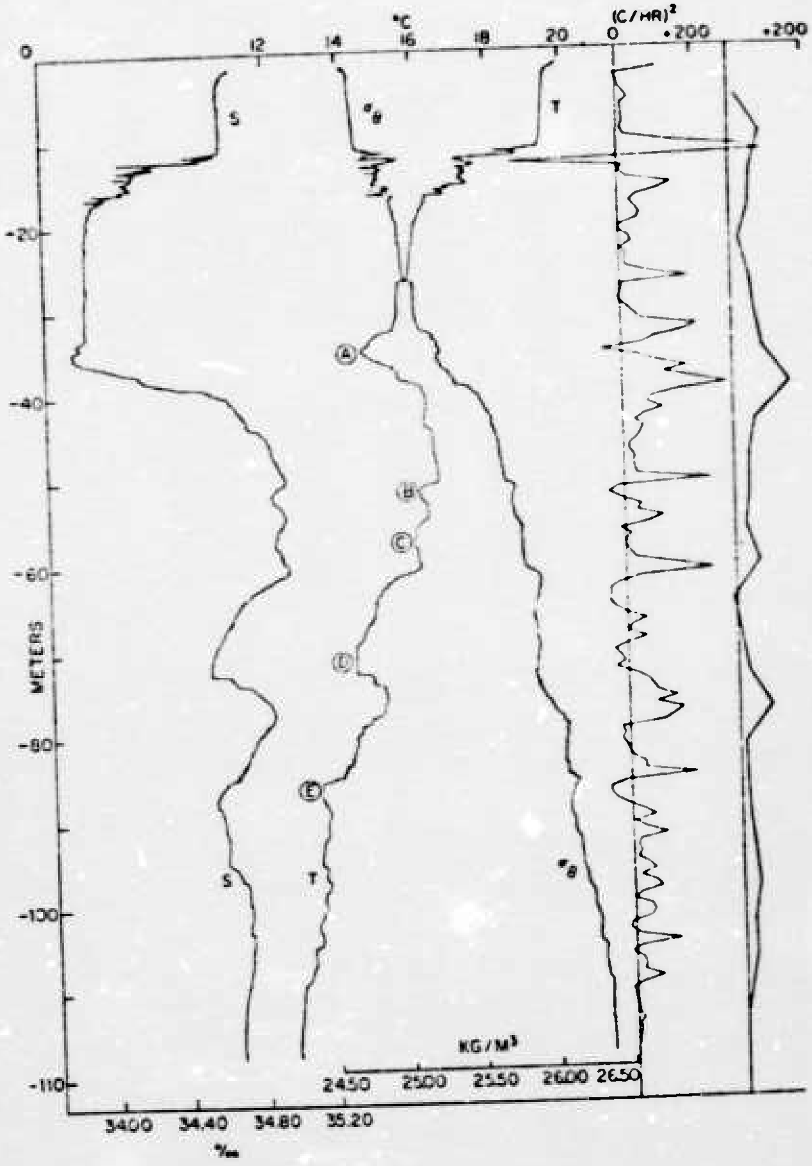


Figure 1b

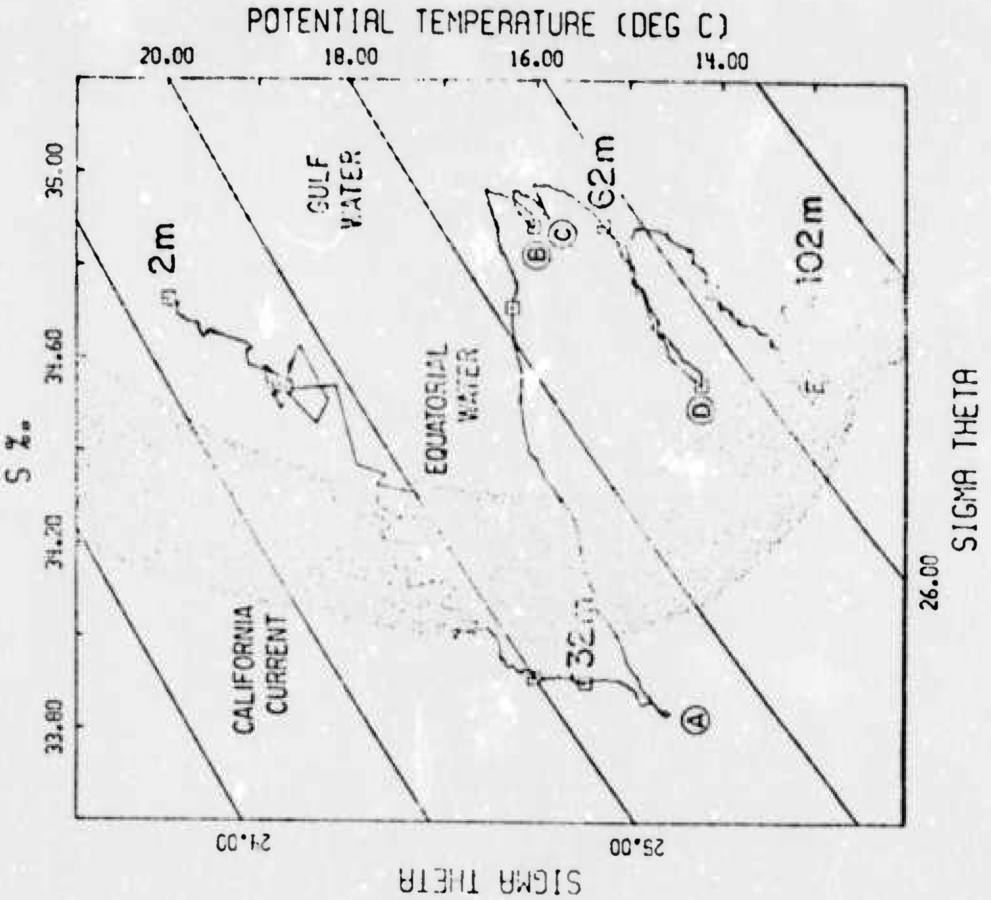


Figure 2b

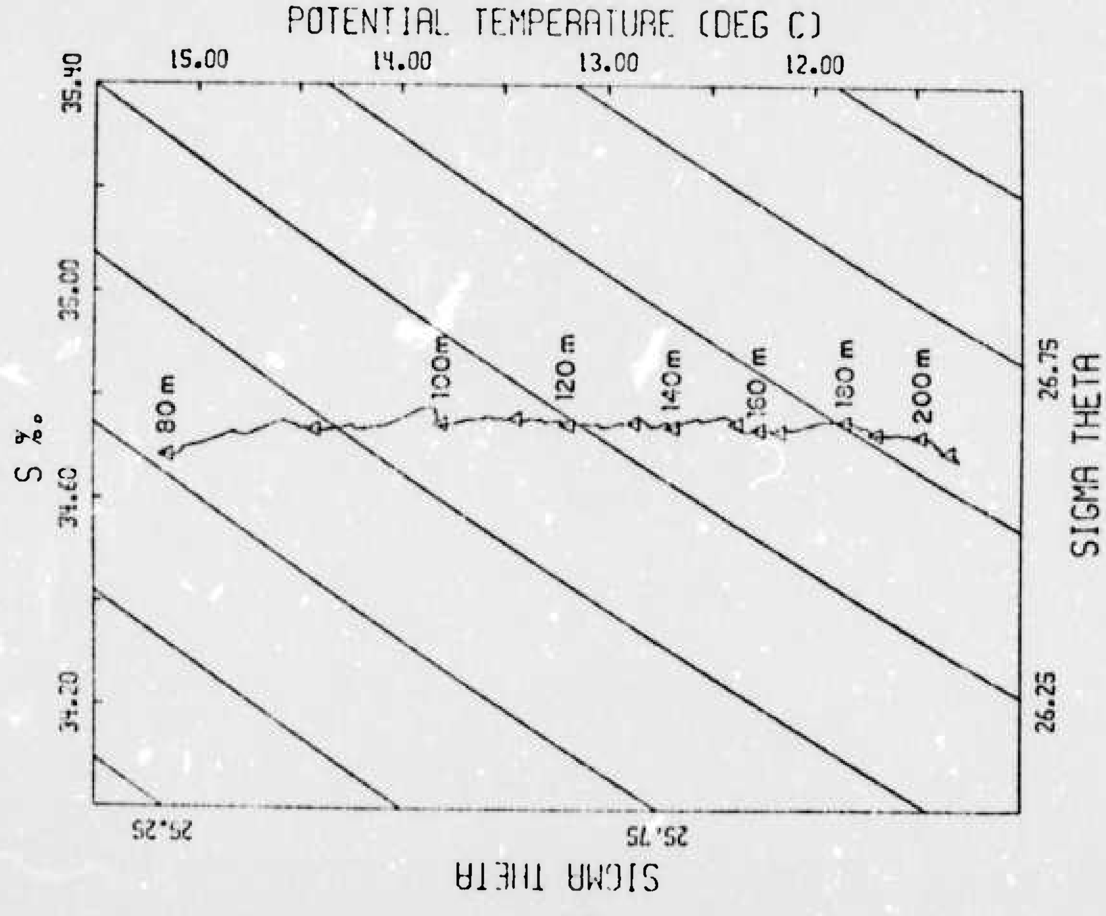


Figure 2a

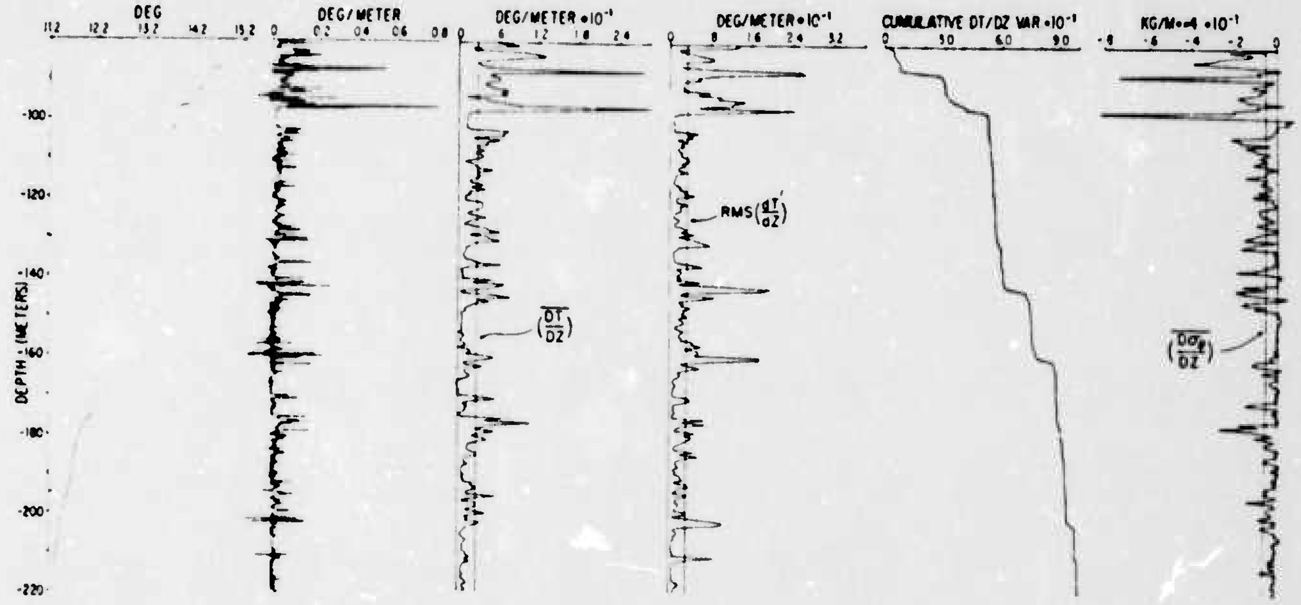


Figure 3a

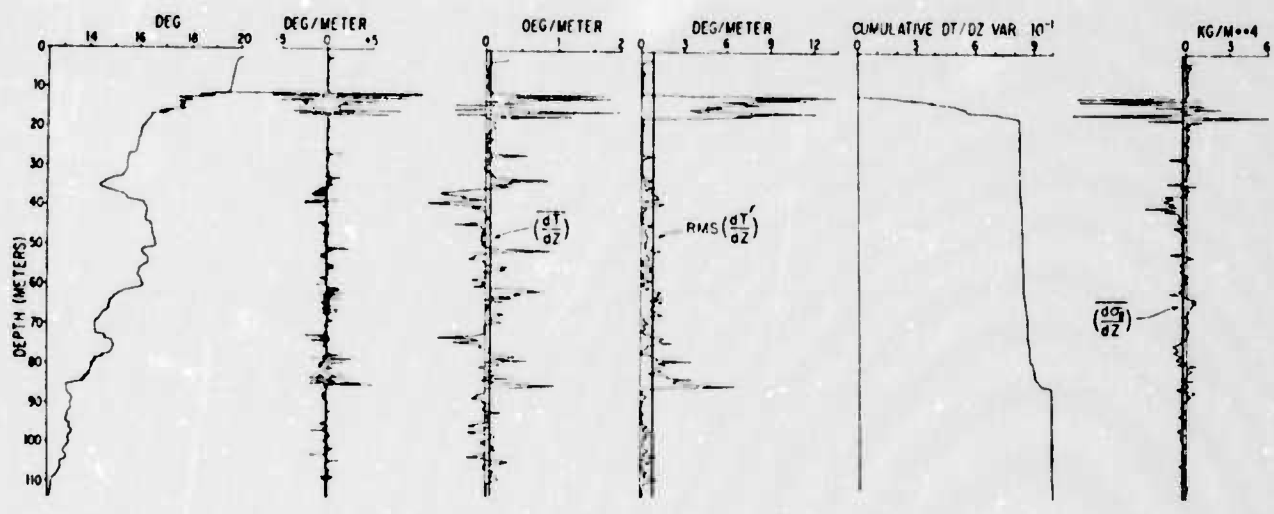


Figure 3b

# PART II: MIDWATER THERMAL STRUCTURE

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This research is conducted by
James L. Cairns and Gordon O. Williams
under the guidance of Drs. Munk and Snodgrass

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## PART II: MIDWATER THERMAL STRUCTURE

### I. PROJECT SUMMARY

This report supplements previous reports on development and use of a freely floating, yo-yoing, instrumented capsule. A summary of work January 1, 1974 through June 30, 1974 is given.

### II. TECHNICAL REPORT

#### 1. Internal Waves

a) Analysis of internal wave data obtained in June 1973 has been completed and is reported in Cairns (1974a, 1974b). A summary of this work follows:

An instrument package has been developed which drifts along freely with the water while repeatedly profiling ocean temperature. Profiling while drifting reduces the Doppler and fine-structure effects which usually contaminate internal wave measurements. Six days of exceptionally clean internal wave records were acquired 280 miles offshore of San Diego, California, in June 1973 at a nominal depth of 800 m. The resulting vertical displacement spectra decrease generally as $\omega^{-2}$ up to the local Brunt-Väisälä frequency. Just below the B-V frequency the spectra drop sharply to low levels. Vertical coherence of internal waves over a separation of 100 m was found to be 0.8, and fairly independent of frequency up to the B-V frequency. An internal wave model proposed by Garrett and Munk is in general agreement with the observed features.

The measured coherence and the nature of the spectrum near the B-V cutoff both are consistent with a concentration of energy in the lower six or so modes.

b) An experiment using this same system is in progress June-July 1974 to acquire internal wave records of nominally 30 days duration. This data will permit adequate resolution of the entire wave spectrum, extending from 1 cycle/day up to about 1 cycle/hour (in the abyssal ocean). This data will also be examined with regard to variability of thermal structure (apart from the role of internal waves).

2. Ocean μ-Structure

Thermal μ-structure (≈ 1 cm resolution) measured with the yo-yoing midwater float at 500 m depth shows the level of activity to be highly variable over the sampled 20 m segment of the water column. Successive traverses of the water column segment reveal distinct regions of high activity which persist in the data for several hours. The whole structure is advected up and down by the internal waves. Plots of quartz temperature gauge data (≈ 20 cm resolution) show numerous temperature inversions of several hours duration with 10 m vertical extent.

Very high μ-structure activity is found in localized regions with vertical extents of order 1 m and lateral extents of order 100 m. The latter figure is based on estimated towing speeds of the sensors due to vertical shear. Each high μ-structure activity region is associated with a temperature inversion of the kind discussed above. However, not every such temperature inversion has an associated region of high μ-structure activity.

The data is suggestive of mixing of intrusive layers, though the present data cannot definitely exclude other mechanisms. Rapid changes of μ-structure and thermal structure suggest a slow drift of the sensors through different "micro-water masses" with sharp boundaries and of small lateral extent. Analysis of this data will be completed and reported in the fall of 1974.

III. REFERENCES

Cairns, J. L. (1974) Internal wave measurements from a midwater float. J. Geophys. Res. (in press).

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## PART III: SURFACE WAVES AND NEAR SURFACE EFFECTS

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## PART III: SURFACE WAVES AND NEAR SURFACE EFFECTS

### I. PROJECT SUMMARY

Primary research efforts in the period January 1, 1974, through June 30, 1974, have been to further analyze data reduced from the successful FLIP cruise of 1973, during which inertial platform measurements of FLIP motions were recorded along with a wide variety of atmospheric, oceanic and surface wave parameters. Turbulent momentum, sensible and latent heat fluxes as well as a variety of small scale turbulence statistical parameters have been calculated without motion corrections or with corrections only for tilting.[1,2,3] The most significant discoveries in the progress of this work are related to the small structure of the temperature and humidity fields, which are strikingly different from those observed in boundary layer studies over land or in the laboratory. Evidence for local anisotrophy of both velocity and temperature fields were observed[3] and connected to the model developed to account for the observations.[1,2]

In addition, work has continued on the development of computational procedures to more completely correct the observations for motions of FLIP. Such corrections are required in order to increase the possibility of detecting second order effects such as the influence of surface and internal waves on the various statistical parameters. Preliminary evidence of the influence of internal waves on near air temperatures in the air and water have been described in earlier reports.

Measurements of turbulence from towed turbulence and temperature detectors have shown strong activity at periods comparable to internal waves[4] as well as weaker activity apparently related to surface waves.[5]

### II. TECHNICAL REPORT

It is clear from partial corrections and approximate calculations that the motion of FLIP significantly contaminates the pertinent data taken in the marine boundary layer over the ocean surface. Thus in order to obtain accurate statistical information, it has become necessary to attempt the full correction. It is expected that the corrected data will be presented within the latter six months of 1974. Although the procedure is complicated and time consuming, it is considered only a means to an end, which is the understanding of air-sea

interaction. In order to distinguish traces of ocean internal waves on the surface, one must also be aware of the normal ambience which is mainly wind waves driven by the turbulent atmosphere.

In the course of analyzing OWAX data, several striking features have been observed and are still under study. Figures 1 and 2 show typical recordings of humidity, temperature and velocity signals. It is apparent that humidity and temperature are highly correlated, and upon calculation these signals are also positively correlated with vertical velocity. Hence, in a statistical sense, warm moist air is rising from the ocean and cool dry air is descending towards the surface. A recurrent feature of the humidity and temperature signals is the appearance of ramp-like structures followed by a sharp drop to an ambient level. In the case of temperature the drops are also associated with puzzling cold spikes. A typical length for the ramp structures has been computed to be 100 meters which agrees well with the wavelength of surface waves in the deep ocean. These observations have lead Gibson and Dreyer to propose a physical model of rolls in the air rising from the ocean surface which are perhaps generated by surface waves, as shown in Figure 3. As the probe travels through a roll, the humidity and temperature should increase until the trailing interface between the warm, humid air and the cool, dry air is reached. Then if the interface is sharp, a drop would occur as is observed in the data. Also the cold spike might be explained by the presence of evaporating water droplets at the interface whereby the latent heat of vaporization cools the surrounding air. It should be emphasized that the above physical model is speculative and requires further substantiation.

The immediate goals upon correction of the data are as follows:

(1) Recomputation of statistical atmospheric data such as spectra and fluxes. It is of interest to determine what fraction of the uncorrected spectra is due to spurious motion and what is genuinely induced by surface wave interaction.

(2) Plotting the corrected traces of various signals simultaneously with the wave height signal. It is hoped that some correlation can be observed of the ramp structures with surface waves. Given the corrected wave height signal, one may then consider conditionally sampling the turbulence with regard to wave height and slope in order to distinguish differences between upstream and downstream surfaces.

The results reported in previous technical reports still stand and remain under investigation. The departure of the temperature spectra from the expected -5/3 slope requires further thought and eventual experimentation. The internal disagreement among the various methods for computing fluxes is expected to improve upon correction for FLIP motion, but it is still suspected that imbalance terms in the energy equations need to be identified and numerically included. A large imbalance term is required for balancing the equation of thermal turbulence.

A research activity not receiving direct support from ARPA at the present time but closely related to ARPA research goals was the participation of C. H. Gibson, J. Schedvin and T. Deaton in the seventh cruise of the DMITRI MENDELEEV for purposes of intercalibration of our turbulence velocity and temperature microstructure detection equipment with the systems used by the Institute of Oceanology groups of the Academy of Sciences of the USSR. Nearly two weeks of ship time was provided by the Academy of Sciences of the USSR to support the intercalibration experiment, which was carried out in the Flinders Current off the coast of Australia between Adelaide and Melbourne at depths between 0 and 1000 meters.

A preliminary account of the experiment by Gibson, Ozmidov, Beyaev and Paka will appear in the Akademy NAUK publication "Oceanology" in the near future. The initial data processing shows the quality of data acquired by both groups is good. High frequency temperature spectra extend well into the dissipation range and imply dissipation rates $\varepsilon$ of 0.03 $cm^2/sec^3$ in temperature gradient regions, to as low as 0.007 $cm^2/sec^3$ in homogeneous layers. $\chi$ values of order $10^{-8}\,{}^\circ C^2/sec$ were obtained from both the US and USSR data, which are reasonable for the conditions of the experiment. Evaluation of the USSR velocity and temperature signals suggest that we should investigate an instrument development project, since the output signals from their hydroresistance anemometer and capacitance conductivity probes for velocity and temperature respectively show sensitivity to $\varepsilon$ and $\chi$ values of about $10^{-4} cm^2/sec^3$ and $10^{-11}\,{}^\circ C^2/sec$ respectively, which is quite good for such rugged, reliable sensors.

## III. FUTURE WORK

Work will continue in the attempts to make complete motion corrections with the inertial platform data from the OWAX cruise. To supplement this project, motion free wind wave information will be obtained in the Institute de Mechanique Statistique de la Turbulence wind-water-wave tunnel in Luminy, France in

September 1974. X-wire anemometer, cold wire temperature, Lyman-$\alpha$ humidiometer and wave probe data will be acquired on analog tape and by the digital computer at the IMST-Luminy Laboratory. Analysis of this motion free data will be coordinated with that from the OWAX cruise. A number of other statistics will also be determined for comparison with the OWAX results; in particular, profiles of the momentum, sensible, and latent heat flux for comparison with various budget equations, measurements of universal similarity parameters (inertial subrange "constants", "constants" characterizing the effects of dissipation variability), and study of dominant physical phenomena ("bursts", "ramps", etc.) which seem to occur in the air-sea boundary layer dynamics.

Work will also continue in the analysis of ocean turbulence data. Luis Vega has good evidence for turbulence produced in phase with surface waves, as well as patches of turbulent temperature widely separated in the horizontal (200-400 meters), which may have some connection to the internal wave field. John Schedvin is analyzing the Russian-US intercomparison data, which we hope to publish jointly with the Russians when we have a chance to exchange results.

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4. L. Vega, Ph.D. Dissertation, "Fine Scale Measurements of Velocity and Temperature in the Upper Layers of the Ocean", in progress.

5. C. H. Gibson, L. Vega and R. B. Williams, "Turbulent Diffusion of Heat and Momentum in the Ocean", submitted to Advances in Geophysics.

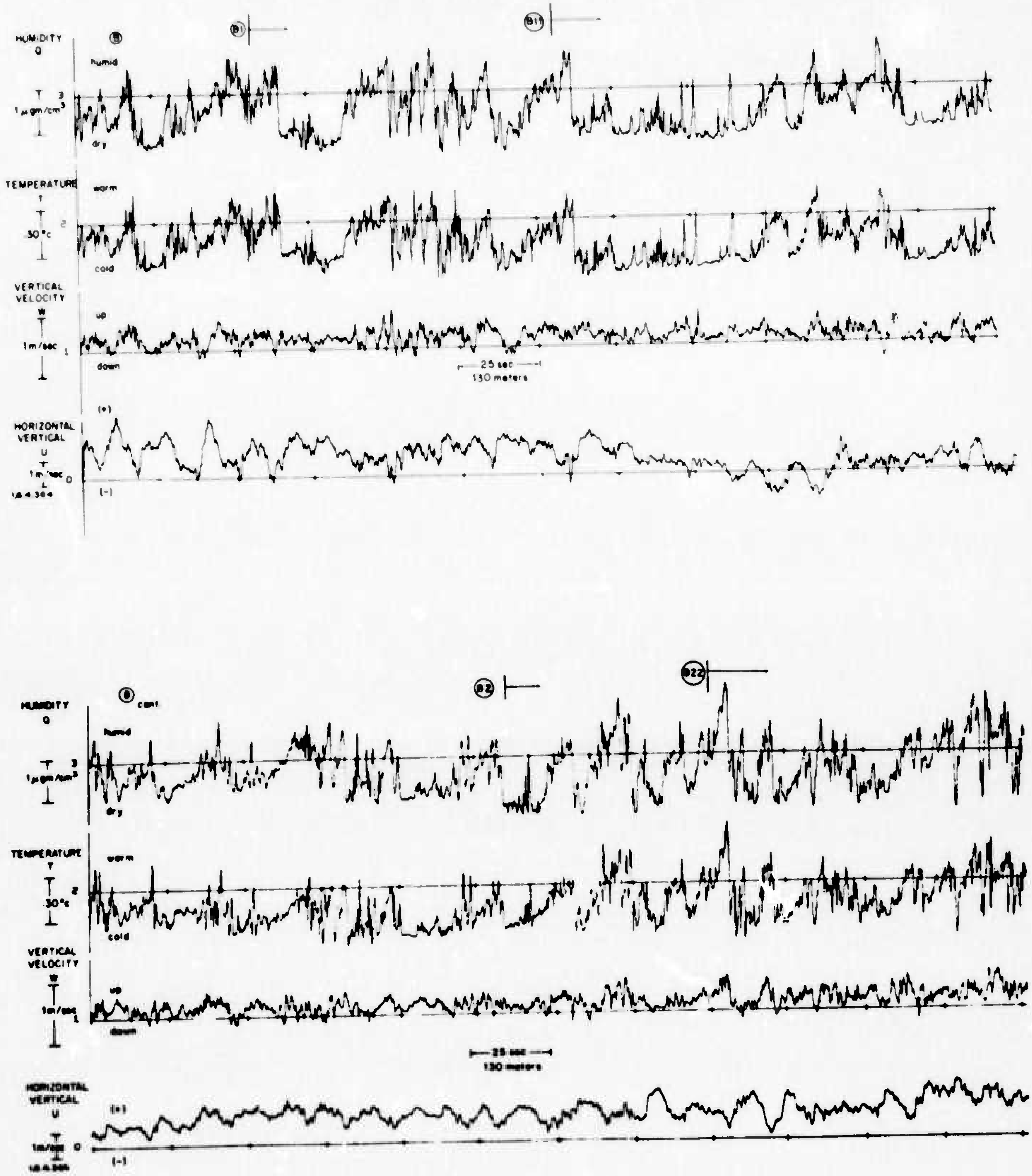
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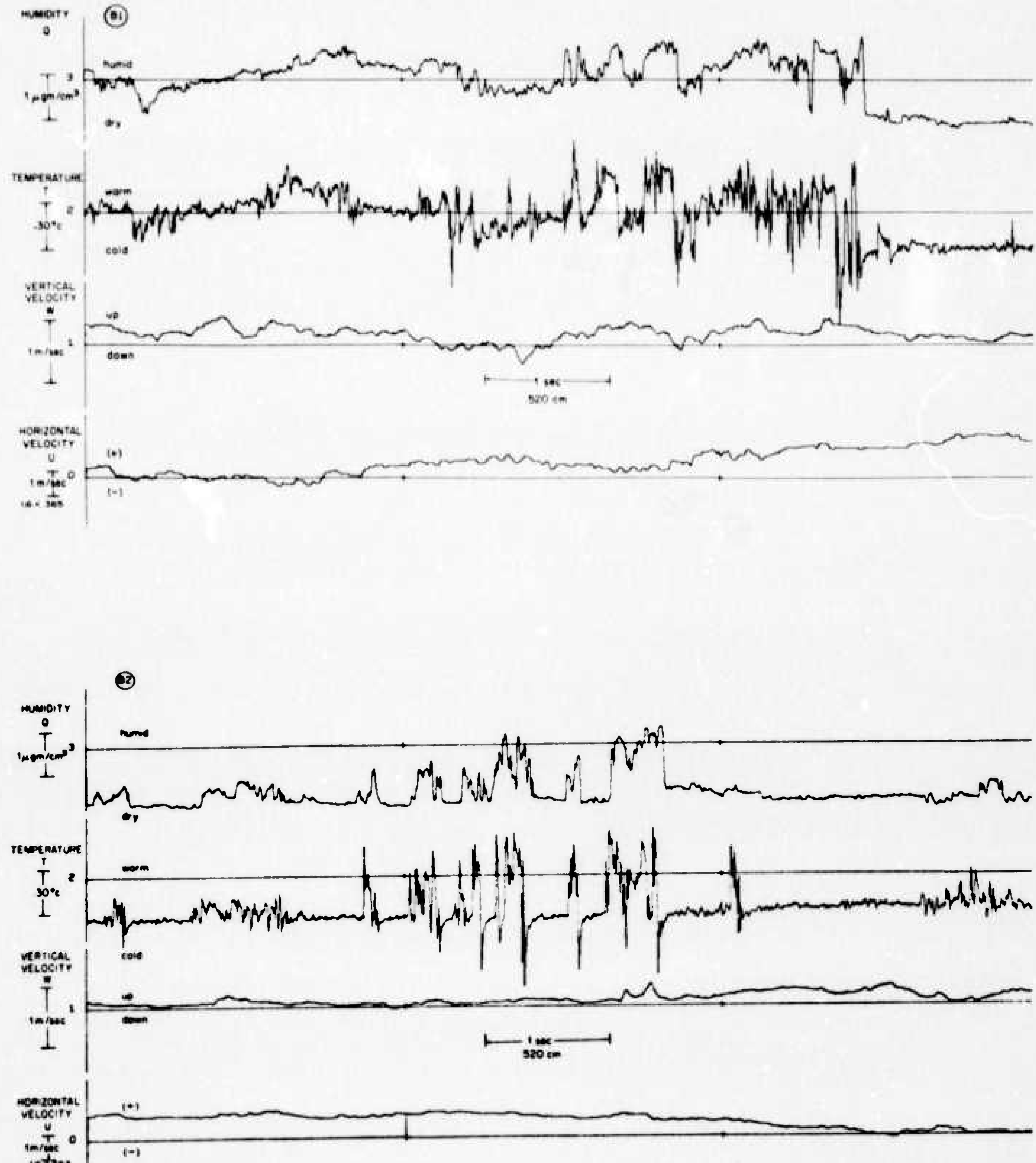
Figure 1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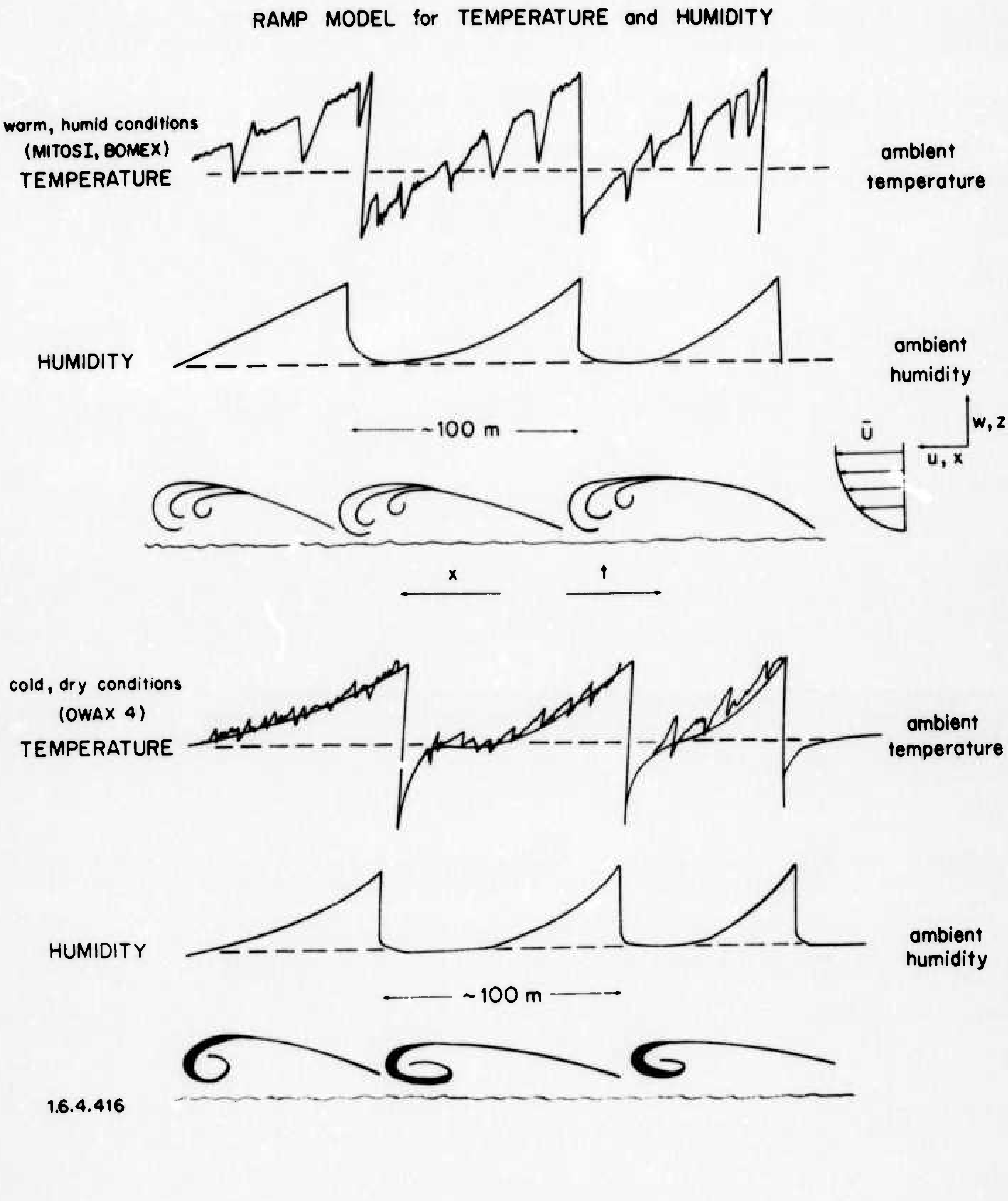
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Figure 3